VISUAL COGNITION, 2005, 12 (6), 878–892

Psychology Press
Taylor & Francis Group

Diagnostic colours contribute to the early stages of scene categorization: Behavioural and neurophysiological evidence

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We examined the effects of colour cues on the express categorization of natural scenes. Using a go/no-go paradigm sensitive to fast recognition processes, we measured early event-related potential (ERP) correlates of scene categorization to elucidate the processing stage at which colour contributes to scene recognition. Observers were presented with scenes belonging to four colour-diagnostic categories (desert, forest, canyon and coastline). Scenes were presented in one of three forms: Diagnostically coloured, nondiagnostically coloured, or greyscale images. In a verification task, observers were instructed to respond whenever the presented stimulus matched a previously presented category name. Reaction times and accuracy were optimal when the stimuli were presented as their original

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This work was supported by grant ARC 01/06-267 (Communauté Française de Belgique—Actions de Recherche Concertées). VG, CJ, and BR are supported by the Belgian National Fund for National Research (FNRS). The authors would like to thank Quoc Vuong for helpful comments on the manuscript.

http://www.tandf.co.uk/journals/pp/13506285.html DOI:10.1080/13506280444000562

diagnostically coloured version, followed by their greyscale version, and lastly by their nondiagostically coloured version. These effects were mirrored in the early (i.e., 150 ms following stimulus onset) ERP frontal correlates. Their onset was delayed for greyscale scenes compared to diagnostically coloured scenes, and for nondiagnostically coloured scenes compared to the other two conditions. Frontal ERP amplitudes also decreased for greyscale and nondiagnostically coloured scenes. Together, the results suggest that diagnostic colours are part of the scene gist responsible for express scene categorization.

Our ability to recognize complex visual scenes is an outstanding property of the human visual system. Under natural viewing conditions, a scene is typically composed of a large number of objects, which can vary in pose, illumination, and occlusions arising from other objects or from cast shadows. To a scene recognition system, the resulting image variations are mostly noise from which diagnostic scene signals must be extracted. To date, this task has eluded all recognition algorithms, except that implemented by the human brain: We recognize complex visual scenes at a glance.

Recently, researchers have turned their attention to the visual information responsible for such effective scene categorization. Several studies have revealed that natural scenes are indeed identified very quickly (e.g., Potter, 1975), as fast as individual objects (Biederman, Mezzanotte, & Rabinowitz, 1982), and from information that can be extracted from a single fixation (Henderson & Hollingworth, 2003). This information, called the ''scene gist'' (or *scene schema*), is hypothesized to act as a representational skeleton that guides subsequent eye movements to further selectively flesh out important scene components (Antes, Penland, & Metzger, 1981; Biederman, 1981; De Graef, de Troy, & d'Ydewalle, 1992; Friedman, 1979; Oliva, Torralba, Castelhano, & Henderson, 2003; Schyns & Oliva, 1994).

The visual information making up the scene gist

Schyns and Oliva (1994) hypothesized that the regularity of spatial organization of scene categories might provide the necessary scene gist for a mechanism to bootstrap scene recognition. Research in early vision suggests that the bases for recognition are low-level visual cues such as luminance, chromaticity, movement, and depth (Livingstone & Hubel, 1987). In line with this suggestion, Oliva and Schyns (1997) and Schyns and Oliva (1994; see also Parker, Lishman, & Hughes, 1992) showed that luminance variations at coarse scales (i.e., ''blobs'') were sufficient to mediate scene recognition without prior recognition of component objects (see Oliva & Torralba, 2001, for a formal analysis). Hence, luminance variations at a coarse scale provide one component of the scene gist.

Another potential component of the scene gist is chromatic variations. However, the role of colour cues for scene and object recognition remains controversial (see Oliva & Schyns, 2000; Tanaka, Weiskopf, & Williams, 2001;

Wichmann, Sharpe, & Gegenfurtner, 2002 for reviews). For example, Delorme, Richard, and Fabre-Thorpe (2000) reported little effect of colour when observers categorized briefly presented (20–30 ms) coloured or greyscale pictures of animals and food. The effects of colour only manifested when the slowest responses and observers were examined. In contrast to luminance cues that are used at an early stage, these results suggest that colour influences a comparatively later stage of scene processing. According to this ''colouring-book'' interpretation, the scene gist would first include luminance variations as a skeleton that is then filled in with appropriate colours.

To establish whether colour contributed to scene recognition, Oliva and Schyns (2000) compared naming and verification performance of natural (e.g., forest, desert) and artificial (e.g., city, motorway) scenes that were presented as normally coloured, abnormally coloured, or greyscale images (see Figure 1). The authors controlled the colour composition of the stimuli using a 3-D colour space (L*a*b space) that separated luminance and chromaticity. Importantly, this separation isolated variations in scene colours from variations in luminance. The colour diagnosticity of scene categories—i.e., the degree of overlap between the colours making up scenes within a category—was also controlled. When colour was diagnostic (i.e., for natural scenes like deserts, forests, coastlines, and canyons), reaction times were faster with normally coloured than with greyscale images, and reaction times in both of these conditions were faster than with abnormally coloured images. Oliva and Schyns (2000) therefore hypothesized that chromatic variations could also be part of the scene gist that indexes scene memory.

There are at least two main reasons why chromatic variations, in addition to luminance variations, would provide an advantage for speeded scene recogni-

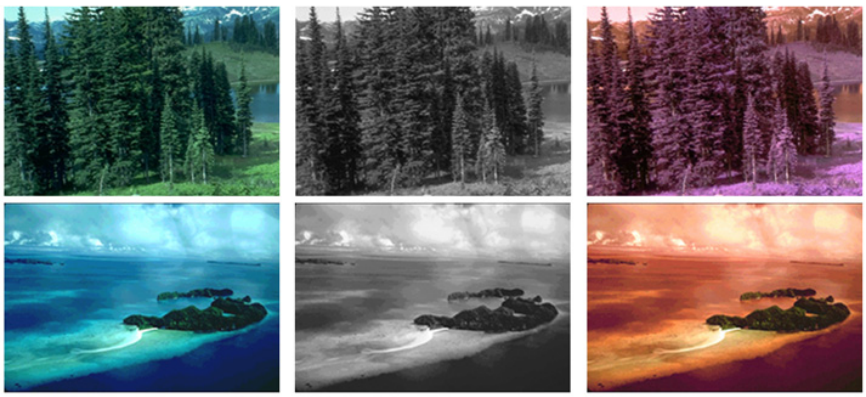

Figure 1. Pictures of natural scenes were used (desert, forest, coastline, and canyon). This figure illustrates the variations of a forest and a coastline picture across the three coloured versions: Normal, grey, and abnormal (from left to right).

tion. The first reason is a simple problem of image segmentation: Chromatic variations provide two additional dimensions (the red–green and yellow–blue colour axes) to segment a scene into its main parts, compared to greyscale versions of the same image. A second advantage is that the additional colour dimension provides supplementary information to index scene memory, speeding up categorization processes when colours are diagnostic of scene categories (Oliva & Schyns, 2000; Tanaka et al., 2001).

Our experiment used diagnostic versus nondiagnostic colouring of the same scenes to tease apart these two possibilities for express scene categorization (segmentation versus memory indexing). We also used greyscale versions of the same scenes to measure baseline performance. In a go/no-go task, we expected to replicate Oliva and Schyns' (2000, Exp. 1) finding obtained in a naming categorization task that recognition of normally coloured scenes was fastest, followed by greyscale scenes, and lastly by abnormally coloured scenes.

In addition to behavioural data (reaction time and accuracy), we also recorded neurophysiological event-related potentials (ERPs) to obtain a more direct measure of the neural processes related to express scene categorization. While typical reaction times in scene recognition tasks are in the range of 400–600 ms (Oliva & Schyns, 2000; Rousselet, Fabre-Thorpe, & Thorpe, 2002; Schyns & Oliva, 1994; Thorpe, Fize, & Marlot, 1996), ERPs reveal, at a much finer temporal resolution (millisecond range), the time course of neural processes underlying categorization. For example, Thorpe and his colleagues (Rousselet et al., 2002; Thorpe et al., 1996; VanRullen & Thorpe, 2001) have shown that express scene categorization was indexed by early ERP activities. In a go/no-go paradigm, observers were instructed to decide whether briefly flashed scenes contained an animal. No-go trials were selectively associated with a frontal negative activity around 150 ms following stimulus onset, suggesting that, at this time, sufficient processing was achieved to perform the categorization task. The ERP technique could thus provide earlier measures of the effects of colour information on scene categorization.

In the present experiment, we investigated whether colour information modulates the time course of scene categorization as early as the fast go/no-go ERP difference reported by Thorpe and his colleagues, thought to reflect the categorization decision. If colour influences the early stages of scene categorization—i.e., the extraction of the scene gist—this response should be modulated by the scene colour content.

METHOD

Participants

Eighteen students from Louvain University (four males, mean age = 24, two left handed), with normal or corrected to normal vision, were paid to participate in the experiment.

Stimuli

Stimuli were presented using Eprime® software on a PC computer monitor. The stimulus set comprised 80 pictures of natural scenes selected from the Corel CD Photo Library (Oliva & Schyns, 2000; see Figure 1). They belonged to four categories of colour-diagnostic scene categories (canyon, forest, coastline, and desert). The computation of colour diagnosticity was based on the L*a*b method detailed in Oliva and Schyns (2000). Twenty exemplars per category represented the scenes from a variety of viewpoints and perspectives. Three different versions of each scene were used in the experiment: Normally coloured (''normal''), greyscale (''grey''), and abnormally coloured (''abnormal''). Abnormally coloured scenes were obtained by first transposing red–green pixels with blue–yellow pixels and vice versa. These transposed images were then inverted, such that red pixels became green, and blue pixels became yellow and vice versa (Figure 1; see Oliva & Schyns, 2000 for technical details on stimulus generation). Thus, 60 images were available for each scene category for a total of 240 stimuli. Luminance—i.e., grey-level means and standard deviations—was kept constant across categories and across these different versions. Viewed at 30 cm from screen, the stimuli (472 × 325 pixels) subtended 15.2° × 10.4° of visual angle.

Procedure

In a go/no-go paradigm, we instructed participants to press a button, as quickly and as accurately as possible, whenever the presented stimulus belonged to a target scene category. The experiment was divided into blocks of 60 trials, and the scene category to respond to varied for each block. A block began with the label of the target scene category (either ''desert'', ''forest'', ''coastline'', or ''canyon''). The order of blocks (i.e., target scene category) was randomized and counterbalanced across participants. Blocks comprised 30 targets randomly interleaved with 30 distractors. We repeated each stimulus four times, twice as targets and twice as distractors. Low-level image properties were thus balanced across go and no-go trials. The experiment comprised 960 trials in total. Trials began with a 100 ms presentation of a scene at the centre of the screen against a black background. Stimulus onset asynchrony (SOA) varied randomly between 1500 ms and 1800 ms.

EEG recordings and analyses

Continuous EEG was recorded from 54 tin electrodes, mounted in an electrode cap (Quick cap). Electrode positions included the standard 10–20 system locations and additional intermediate positions. During EEG recordings, all electrodes were referenced to the left mastoid. Impedance was kept below 10 kΩ. EEG signal was sampled at a rate of 1024 Hz. EEG signal was rereferenced offline relative to linked mastoids and linearly detrended in order to

eliminate baseline drifts on frontal and central electrodes. The epochs were excluded from averaging if the standard deviation of the EEG within a sliding 200 ms time window exceeded 35 μV. Incorrect-response trials were also excluded. For 11 participants, ERPs were corrected for eye blinks by the subtraction of PCA-transformed EOG components for each electrode, weighted according to EOGV propagation factors (computed via linear regression; Nowagk & Pfeifer, 1996). This procedure resulted in a mean number of 147 ($\pm$ 2.5) trials per participant and condition. Electrodes were grouped into frontal (left: FP1, F1; right: FP2, F2; midline: FPZ, FZ, according to 10–20 system nomenclature) and parietal (left: P1, P3, PO3; right: P2, P4, PO4; midline: PZ, POZ) groups according to position. We computed four ERP difference waveforms for each participant: (1) Go minus no-go trials, independently of colour conditions; (2) go minus no-go trials in the normal condition, (3) go minus no-go trials in the abnormal condition, and (4) go minus no-go trials in the grey condition.

Statistical analyses

Repeated-measures analyses of variance (ANOVAs) were performed on behavioural go responses (RT and accuracy) with colour (normal versus abnormal versus grey) as a within-subjects factor. ERP data were analysed according to previous studies that used the go/no-go response paradigm (e.g., Thorpe et al., 1996; VanRullen & Thorpe, 2001). Intrasubject *t*-tests ($df = 17$) were performed at the $p < .05$ level between -100 and 600 ms on the four differential waveforms and for the nine averaged electrodes. This analysis enabled the precise tracking of categorization effects on onset latencies across the colour conditions. We further characterized the go/no-go differential activities across colour conditions in terms of their amplitude, by computing pairwise intrasubject *t*-tests between normal, grey, and abnormal differential waveforms. Overall, an effect was considered to be significant if 30 consecutive *t*-values (29.2 ms here) were below the $p < .05$ level (Rugg, Doyle, & Wells, 1995).

RESULTS

Behavioural results

The behavioural responses were fast and accurate (Figure 2), indicating that our categorization task effectively tapped express scene perception. Despite the ease with which participants categorized scenes, task performance was influenced by the colour content of the scenes. Response times significantly differed across colour conditions, $F(2, 34) = 141.7$, $p < .0001$. They increased from the normal condition (median: 427.5 ms; mean: 428.4 ms $\pm$ 15 ms, following stimulus onset) to the grey condition (median: 459 ms; mean: 461.2 ms $\pm$ 15 ms),

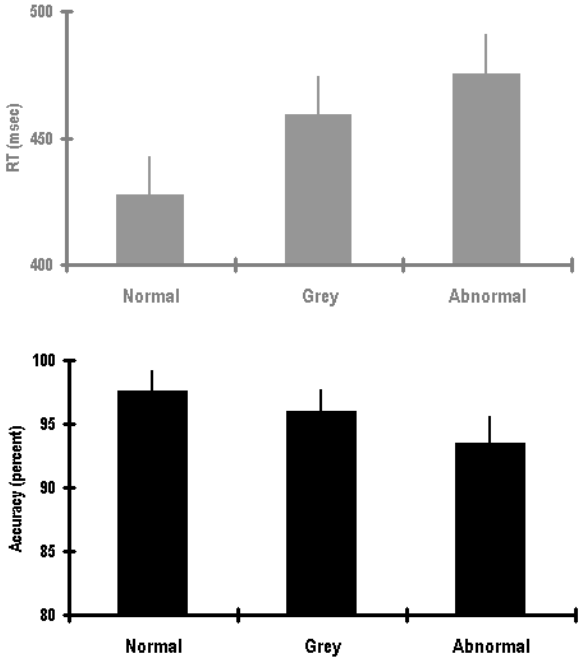

Figure 2. These histograms illustrate the influence of colour on go mean response times (RTs, in ms, top) and accuracy (bottom); $n = 18$. The bars indicate the standard errors (in ms).

$p < .0001$, and they were longest in the abnormal condition (median: 475.5 ms; mean: 484 ms $\pm$ 15 ms); grey–abnormal contrast, $p < .0001$.

Although participants performed at ceiling, accuracy also revealed systematic variations across colour conditions, $F(2, 34) = 24.1$, $p < .0001$. Accuracy decreased from the normal (97.5% $\pm$ 1.7%) to the grey conditions (96% $\pm$ 1.8%), $p < .003$, and it reached its lowest level in the abnormal condition (93% $\pm$ 2.2 %); grey–abnormal contrast: $p < .001$. Overall, the false alarm rate was very low (3.2% $\pm$ 0.6 %), and was not influenced by picture colour, $F(2, 34) = 1$, $p > .37$.

In summary, the behavioural results indicated that the colour content, rather than the mere presence or absence of chromatic cues, affected the speed and accuracy of express scene categorization. Although the absence of colour decreased performance relative to a normally coloured scene, an incongruent colour content, such as in the abnormal condition, produced an even larger interference. These results replicate Oliva and Schyns' (2000) findings and confirm the important role of diagnostic colours when observers categorize natural scenes at a glance.

Neurophysiological results

The comparison of go and no-go trials, with colour conditions collapsed, led to strong ERP differential activities (Figure 3). In agreement with Thorpe et al.'s results (Rousselet et al., 2002; Thorpe et al., 1996; VanRullen & Thorpe, 2001), no-go trials led to larger negative activities at approximately 150–200 ms following stimulus onset (Figure 3). The go/no-go difference is first evident on frontal electrodes (midline frontal), as soon as 147 ms following stimulus onset, and continued 420 ms on average poststimulus onset. The next consistent differential activity occurred at parietal sites approximately 300 ms after stimulus onset and persisted approximately until 500 ms post onset; 400 ms following stimulus onset, a negative differential component was observed on frontocentral electrodes (see Figure 3). However, several aspects strongly suggest that this negative difference did not constitute an early correlate of scene categorization, and was not analysed further. First, it was related to the go and no-go waveforms returning back to baseline after their early categorization-related differentiation (see for example Fz box in Figure 3). Second, its late latency actually overlapped with manual response execution. Finally, this negative difference displayed a highly restricted scalp distribution since it was only significant on FC1 and FCz electrodes.

We examined the effect of colour content on the frontal and parietal differential responses by tracking the onset latency of significant go/no-go differences for each colour condition separately (Figures 4 and 5). In the normal colour condition, the frontal difference occurred as soon as 137 ms (averaged onset latencies across left, right, and midline locations). The parietal difference occurred around 140 ms later, at 276 ms. Overall, the onset latencies of go/no-go differences were consistently delayed in the grey and abnormal colour conditions (Figures 4 and 5). The frontal ERP difference started at 184 ms on average in the grey condition and at 226 ms on average in the abnormal condition. On frontal sites, the grey condition thus revealed intermediate onset latencies between the normal and abnormal conditions. Parietal sites revealed large delays between the normal condition, on the one hand, and the abnormal and grey conditions, on the other hand. The first parietal go/no-go difference occurred at 327 ms in the grey condition, and at 323 ms in the abnormal condition (on right parietal electrodes; Figure 4).

As can be seen in Figures 4 and 5, not only did scene colour contribute to onset latency modulation of the experimental effects, it also influenced the magnitude of these effects. When comparing the differential waveforms observed for the three colour conditions separately (Figure 4), normally coloured images led to the largest differential activities on frontal and mostly on parietal sites. It differed from greyscale or abnormally coloured images at around the same latencies (200 ms, on average, on frontal sites and 302 ms, on average, on parietal sites). The abnormal and grey conditions differed later, at

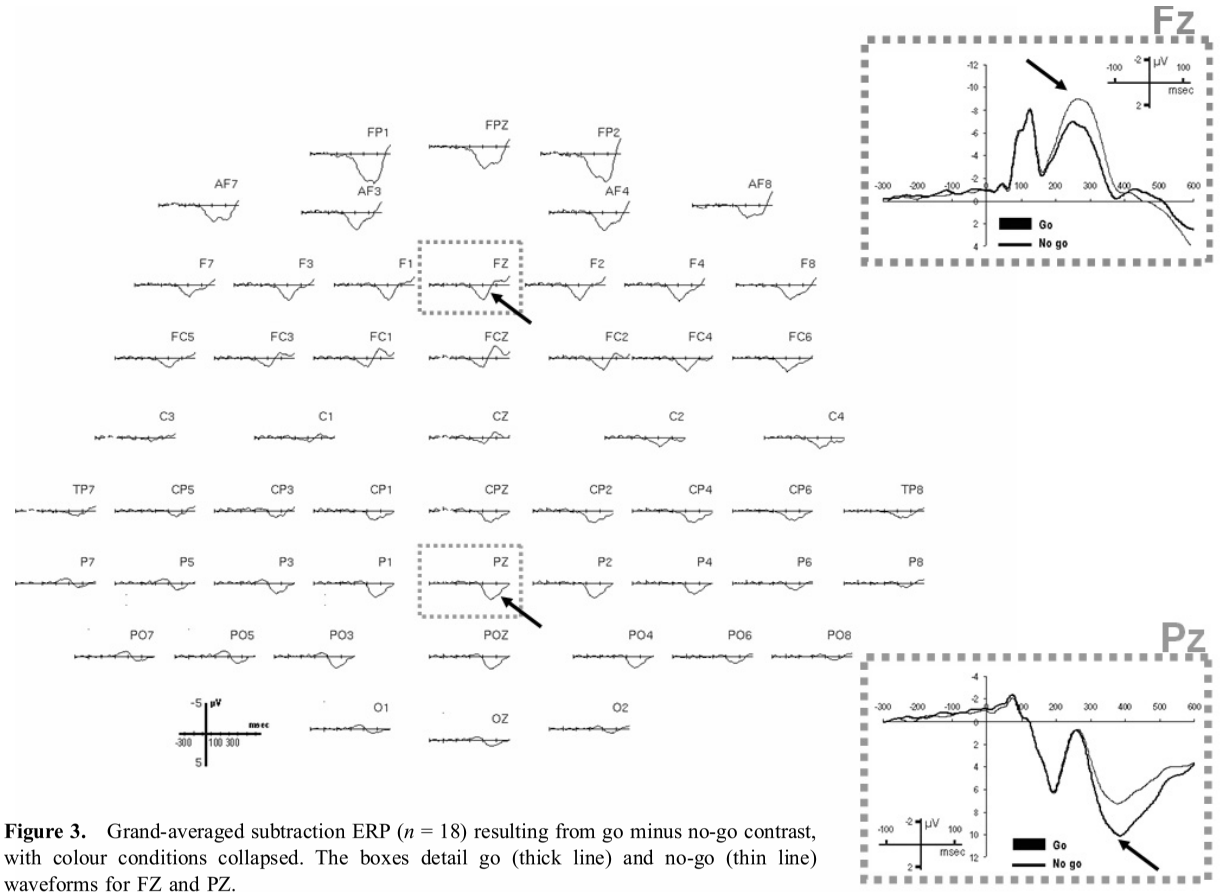

Figure 3. Grand-averaged subtraction ERP (n = 18) resulting from go minus no-go contrast, with colour conditions collapsed. The boxes detail go (thick line) and no-go (thin line) waveforms for FZ and PZ.

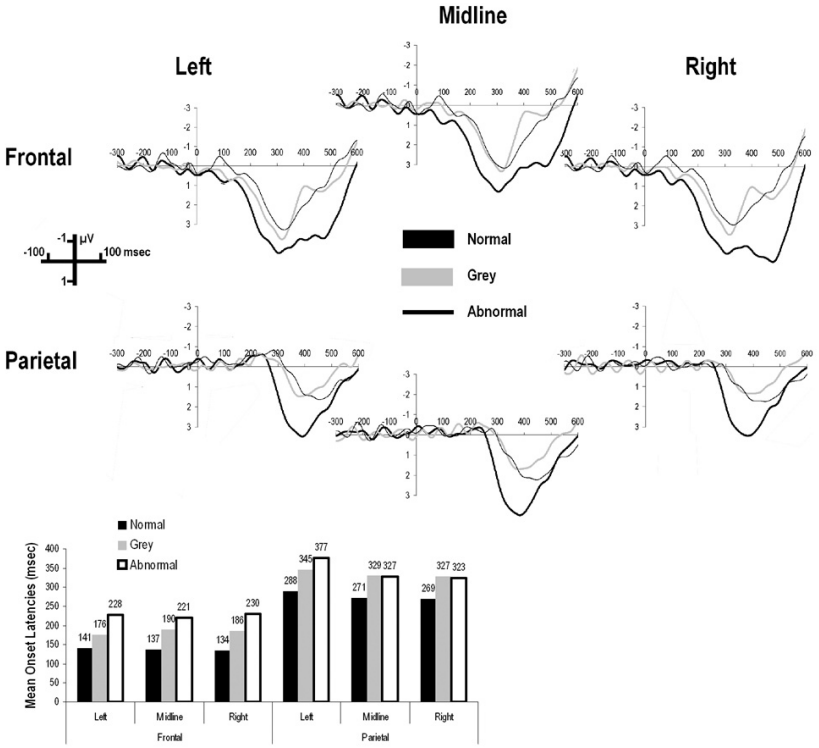

Figure 4. Top: This figure displays the waveforms resulting from go minus no-go ERPs subtraction (n = 18), computed for each colour condition separately and for each scalp electrode site. A 20 Hz low-pass was used for the display. Bottom: Histograms displaying the onset latencies of significant go–no-go statistical differences for colour conditions separately.

251 ms, on average, on frontal electrodes and 371 ms, on average, on parietal electrodes.

In summary, millisecond-by-millisecond statistical analyses revealed that the onset latencies of scene categorization neurophysiological correlates were consistently delayed for abnormally coloured or greyscale images conditions as compared to normally coloured images. The amplitude of these differential activities was also significantly larger for normally coloured images, as compared to abnormally coloured or greyscale images. The onset latency of go/no-go differences was delayed in the grey and abnormal conditions, but the latter condition revealed the most delayed latencies, at least at frontal sites. Grey and abnormal conditions differed later and to a lesser extent at the level of the amplitude of differential activity. In conjunction with the behavioural results, these neurophysiological results suggest that it is the diagnosticity of the colour

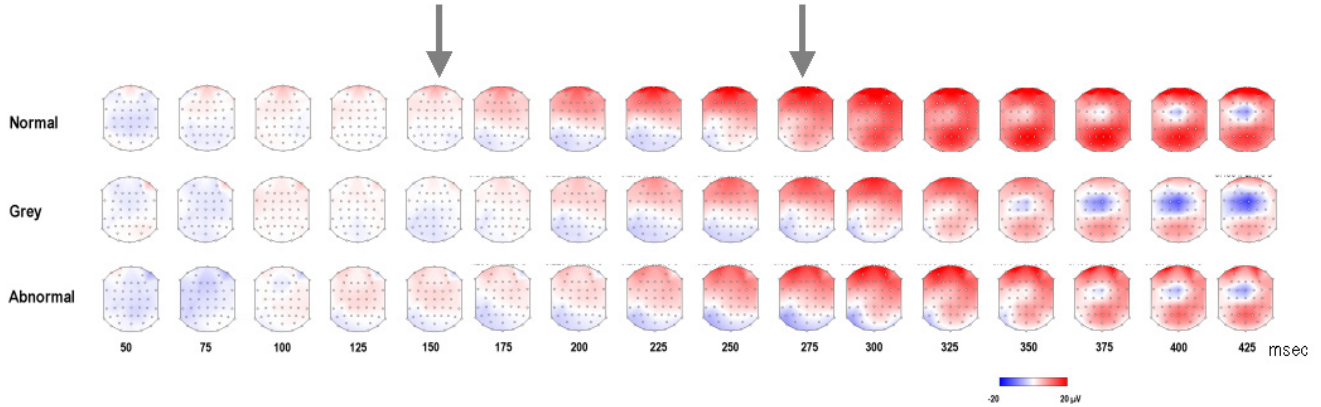

Figure 5. Scalp topographies of differential waveforms, obtained through the go minus no-go trials ERP subtraction (n = 18), are displayed for each colour condition separately. The first arrow indicates the approximate onset of frontal differential activity and the second one indicates the onset of parietal differences for normal condition.

content that contributes to express scene categorization rather than the mere presence of chromatic cues.

DISCUSSION

The aim of the present study was to examine express scene categorization by systematically manipulating the colour content of natural scenes. Behavioural responses were fast and accurate, confirming that our paradigm tapped into express categorization processes. Median RT for scenes presented in their diagnostic colours (427.5 ms in the normal condition) was indeed within the time range reported by Delorme et al. (2000; $\pm$420 ms), Rousselet et al. (2002; 390 ms), Thorpe et al. (1996; 445 ms), and VanRullen and Thorpe (2001; 350 ms), despite dissimilarities in the categorization tasks and measurement apparatus.[1] Consistent effects of colour were observed on categorization with performance being improved (versus worsened) when scenes were shown in their diagnostic (versus nondiagnostic) colours, compared with the baseline greyscale condition. These results obtained in a go/no-go scene verification task replicated those obtained with a naming task by Oliva and Schyns (2000). Thus, we can be reasonably sure that colour helps the speeded categorization of colour-diagnostic scenes.

By measuring the neurophysiological responses underlying categorization at a high temporal resolution, we clarified the stage at which chromatic information influences scene categorization. In line with previous reports (Rousselet et al., 2002; Thorpe et al., 1996; VanRullen & Thorpe, 2001), scene categorization was associated with consistent and early ERP differential activities for go and no-go trials. These differential activities occurred as soon as 150 ms on frontal electrodes, showing that sufficient processing was accomplished at this latency for participants to decide whether or not the scene belonged to a given target category. A second go/no-go difference was initiated on parietal sites at around 300 ms. This latter differential activity can be identified as a P300, a large positive component involved in both stimulus processing and response selection (for a review see Verleger, 1997) and has been described previously in a go/no-go discrimination task (Roberts, Rau, Lutzenberger, & Birbaumer, 1994).

What processing stage may early ERP frontal differential activity reflect? The onset latency of the ERP frontal activity largely preceded the motor output (which occurred at 458 ms on average) and so it is unlikely that this activity

[1] Using a sophisticated infrared diodes touch sensitive apparatus, Thorpe et al.'s experiments measured the onset of button releases, a much faster response than button presses as in the present experiment. Previous go/no-go experiments also used a different type of task where participants had to detect a particular object (an animal, for example) in the scenes. In the present experiment, we instructed participants to decide whether the scene, considered as a whole, corresponded to a target category.

relates to motor activations involved in response execution (see also Thorpe et al., 1996). Low-level visual differences between the conditions cannot account for these activity differences either, given the conditions comprised exactly the same stimulus sets, once presented as target, and once as nontarget (as in VanRullen & Thorpe, 2001). Thus, in line with previous studies, we can attribute frontal differential ERP activities as an index of the lowest processing time limit at which scene categorization is accomplished by the brain.

The colour content of scenes modulated the onset latencies and amplitudes of the frontal ERP differential activities. They were delayed by about 46 ms with greyscale scenes compared with diagnostically coloured scenes, and an 89 ms average shift was observed with nondiagnostically coloured scenes. This finding clearly demonstrates that diagnostic colours do speed up early categorization processes, which then give rise to faster behavioural responses. Note that two further conclusions can be made from the design of the experiment: (1) The colour-related ERP modulations do not stem from disparities in scene luminance gradients, because these were exactly matched across the different colour conditions; and (2) the ERP modulations do not arise simply because coloured images are easier to segment than greyscale images—nondiagnostic colours gave rise to the longest shifts and lowest amplitudes. Briefly stated, our results indicate that diagnostic colours provided faster indexing of scene memory and that this categorization can be accomplished by the brain within the first 150 ms of visual processing (see Gegenfurtner & Rieger, 2000 for supportive evidence). Such colour contribution to express scene categorization should be located at a visual processing stage where the stored knowledge of scene colour properties is represented.

A recent electrophysiological investigation in monkeys might provide more indications about the precise stage of visual processing in which diagnostic colours is involved (Edwards, Xiao, Keysers, Foldiak, & Perrett, 2003). Compared to diagnostically coloured face pictures, a majority of inferotemporal (IT) face selective cells (70%) displayed significantly reduced responses not only for greyscale face images, but also when faces were presented in nondiagnostic colours. In the latter condition, the cells' response amplitudes were lowest. This response difference was evident from stimulus onset (median 91 ms latency), suggesting that information about diagnostic colour is processed at the same time as object shape in monkey IT cortex. These findings support the idea that diagnostic colour information is an integral part of the visual processing of complex shapes (see also Zeki & Marini, 1998).

CONCLUDING REMARKS

Our results demonstrate that the neurophysiological processes underlying scene categorization use diagnostic colours as soon as 150 ms. The reported latency of frontal differential activities, together with the evidence for the involvement of

IT in diagnostic colour coding (Edwards et al., 2003; Zeki & Marini, 1998), suggest that express scene categorization relies on the fast extraction of a scene gist comprising not only the luminance information giving the global scene structure, but also its diagnostic colour content.

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